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Patent holder:
Rhode & Schwarz GmbH & Co. KG 81671 München, DE

Representative:
Mitscherlich & Partner, Patent Attorneys and Attorneys at Law,
80331 München

Inventor:
Erhardt, Thomas, 81667 München, DE

Publications taken into consideration when judging patentability:

DE	44 20 376 C2
DE	34 15 152 A1
US	58 47 619 A
US	47 17 894 A
US	58 61 781
US	48 90 301
US	48 16 783

Quadrature mixer with adaptive error compensation

In a quadrature mixer with which the quadrature components of a ZF input signal are converted by mixing with two superposition frequencies, in quadrature relative to one another, of a local superposition oscillator into an output signal, the output signal is converted by means of an analog IQ demodulator to the intermediate frequency of the input signal and subsequently, from the quadrature components recovered in this way, in the intermediate frequency position a) the I and Q offset error is determined, b) by means of intermediate frequency band filter and succeeding rectifier the imbalance error is determined, and c) by multiplication of these b) obtained signals, the quadrature error is determined;
from these offset, imbalance and quadrature error values determined in this way, lastly, correction values are determined in a regulator, with which the quadrature components of the intermediate frequency input signal are continuously (adapatively) corrected in error-compensating manner without the useful signal being impaired.

Specification

The invention relates to a quadrature mixer according to the preamble of the independent claim.

Quadrature mixers are increasingly more frequently applied in high-frequency transmission technology. Through the principle of quadrature mixing a side band is completely suppressed in ideally operating mixers. However, due to the so-called offset, imblance and quadrature errors, in practice, a quadrature mixer does not operate ideally and the suppression of a side band as well as of the residual carrier is not optimal, such that these signals appear as disturbance signals at the output of the mixer. While it is known to calibrate such quadrature mixers before use by means of level detectors or spectrum analyzer (US 47 17 894 or US 5 847 619), regulating out these errors without interruption or impairment of the output signal is not possible with these known methods.

The invention addresses the problem of providing a quadrature mixer with which without impairment of the useful signal the disturbing offset, imbalance and quadrature errors can be continuously (adaptively) compensated.

Starting from a quadrature mixer according to the preamble of the independent claim, this problem is solved through its characterizing characteristics. Advantageous further developments are evident in the dependent claims.

Without impairing the useful signal the offset, in a quadrature mixer according to the invention imbalance and quadrature errors are continuously determined in a very simple manner by an analog IQ demodulator, which supplies the detected errors with their correct signs to a regulator, in which subsequently the corresponding correction values for the compensation of the quadrature components I and Q of the modulated ZF input signal are generated.

$I(t) = IM(t) \cdot \cos(\omega_{ZF} \cdot t) + QM(t) \cdot \sin(\omega_{ZF} \cdot t)$

$Q(t) = IM(t) \cdot \sin(\omega_{ZF} \cdot t) + QM(t) \cdot \cos(\omega_{ZF} \cdot t)$

According to the invention thus said errors are automatically regulated out, i.e. an adaptive error compensation takes place. The principle according to the invention can be applied with analog ZF input signals as well as also with digital ZF input signals, which, for example, are generated by means of a digital IQ modulator. In the latter case it is advantageous to convert directly at the output of the IQ demodulator the error values generated there into the corresponding digital values, such that the regulator can also be developed as a pure arithmetic unit for processing the error values and for generating the correction values.

In the following the invention will be explained in further detail in conjunction with schematic drawings with reference to embodiment examples.

Figure 1 depicts the basic circuit diagram of a quadrature mixer 1, which is comprised of two mixers 2 and 3, to which is supplied at the input side the quadrature components I and Q as modulated ZF input signals from an IQ modulator 4, to which, in turn the base band signals IM and QM are supplied as modulation signals. A local superposition oscillator 5 generates a carrier frequency f_{LO}; by means of a 90° phase shifter 6 two superposition frequencies in quadrature with respect to one another are generated, which are supplied to mixers 2 and 3. The output signals formed in this way are added in an adder 7 to form an output signal A.

In the quadrature mixer 1 the ZF input signals I and Q are converted into the frequency $f_{RF} = f_{LO} + f_{ZF}$ of the useful signal NS. Due to offset, imbalance and quadrature errors, the quadrature mixer 1 does not operate ideally and the lower side band SB is not completely suppressed at the frequency $f_{LO} - f_{ZF}$, a residual carrier TR also remains at the frequency f_{LO} and these signals SB and TR appear in the output signal A as disturbance components, as is shown in Figure 2a.

According to the invention the output signal A is supplied to an IQ demodulator 10, in which it is again converted back across two mixers 11 and 12 through two superposition frequencies f_{LO}, in quadrature with respect to one another, of the superposition oscillator S

into the IQ components I' and Q' with the same intermediate frequency ZF with which the input signal is also supplied to the quadrature mixer 1. These reconverted quadrature components I' and Q' at the output of the IQ demodulator are supplied once via lowpass filters 13 and 14 directly to a regulator 15; they consequently correspond to the I or Q offset. Via lowpass filters 16 and 17, which are tuned to the intermediate frequency f_{ZF}, the I and Q signals are filtered out and via peak value rectifiers 18 and 19 also supplied to the regulator 15 for determining the imbalance error. In addition, the filtered I and Q signal is supplied to a mixer 20 and in this way the quadrature error is determined, which is supplied across a further lowpass filter 21 to regulator 15. In the regulator 15 the error values determined thus of the quadrature mixer 1 are evaluated and converted into correction values, through which the I and Q components are corrected such that the offset, imbalance and quadrature errors of the quadrature mixer 1 are compensated and regulated out. Via the mixers 22, 23 the imbalance error is corrected, via the adder 24, 25 the offset error, and, through the effect onto the 90° phase shifter 6, the quadrature error.

The direct conversion depicted in Figure 1 in the basic circuit diagram of the output signal A, which most often can be varied in frequency, in the IQ demodulator and the subsequent evaluation of the quadrature components I' and Q' would in practice be difficult with varying frequency. It is therefore useful to convert the output frequency A, variable with the superposition frequency f_{LO}, into a fixed intermediate frequency by interconnecting an additional mixer. For that purpose an additional superposition oscillator following along with the superposition oscillator 5 is required, to which a frequency can be tuned which is synchronous with the frequency f_{LO}, however relative to it, offset by a predetermined constant intermediate frequency.

Figure 3 shows an embodiment example reduced to practice of a quadrature mixer according to the invention. The input signals supplied as digital signals in the base band are converted in a digital IQ modulator 4 with the aid of a frequency synthesizer DDS into the quadrature components I and Q to the intermediate frequency f_{ZF}. After passing through mixers 22, 23 and adders 24, 25 the digital signals are again converted into analog signal by

means of digital-to-analog converters 32 and 33 and supplied as input signals to the quadrature mixer 1 and there converted with the adjustable superposition frequency f_{LO} of the superposition oscillator 5 into the useful signal at the frequency $f_{RF} = f_{LO} + f_{ZF}$ at the output A. The output signal is supplied to an additional mixer 30, in which the output signal is converted with an unmodulated superposition frequency $f_{CW} = f_{LO}$ {illegible} f_{IF} however following along with the superposition frequency f_{LO}, to a fixed intermediate frequency f_{IF} + f_{ZF}. The superposition frequency f_{CW} is generated in the superposition oscillator 31. With the superposition oscillator 34 the fixed superposition frequency f_{IF} for the IQ demodulator 10 is generated. Via lowpass filters 13 and 14 from these ZF signals the offset signals are filtered out and supplied to regulator 15 across the analog-to-digital converters 36, 37. Via the bandpasses 16, 17 the I and Q signal is filtered out and across peak value rectifiers 18, 19 and the analog-to-digital converters 38, 39 also supplied as imbalance errors to regulator 15. After filtering in a lowpass filter 21 and digitization in the analog-to-digital converter 40, with a mixer 20 the I and Q signals are supplied as quadrature error to regulator 15. Figures 2c and 2d show the operational mechanism of this error signal processing by the band passes 16, 17 and the lowpass filter 21.

In order to consider in the regulation the inherent errors of the IQ demodulator 10, in a preceding calibration process these inherent errors can also be determined and stored in regulator 15 and in the subsequent regulation be taken into account accordingly without impairing the useful signal NS. For this purpose, in front of the IQ demodulator 10 a highpass filter 41 alternatively interconnectable is provided, which can be connected via a switch 42 alternatively preceding the IQ demodulator 10. In front of this highpass filter 41 additionally a further lowpass filter 43 is provided. According to Figure 2b with the lowpass filter 43 at the output of mixer 30 the upper mixed product is filtered out, the lower mixed product is supplied to the IQ demodulator 10 alternatively directly or across the highpass filter 41. With the highpass filter 41 switched on, according to Figure 2b the lower side band SB and the residual carrier TR is filtered out, such that at the demodulator output only the error signals are present, which the IQ demodulator 10 itself produces through its analog

technology (offset voltages, phase errors, unequal damping and the like). These errors are stored as a rule in regulator 15 and in the subsequent regulation proper (with the highpass filter 41 switched off) taken into consideration accordingly. In an alternative calibration process for the IQ demodulator via switch 44 the sinusoidal signal of an oscillator 46 with frequency $f_{IF} + f_{ZF}$ is supplied. This is the center frequency of the useful signal at the input of the IQ demodulator. In the embodiment example according to Figure 3 in the regulator 15 digital correction values are generated from the digitally supplied error signals directly, in this example thus the correction proper takes place directly digitally, only for the generation of the quadrature error signal a reconversion into an analog signal by means of a digital-to-analog converter 44 is required.

In order for the useful signal f_{RF} not to be impaired during the calibration process, the regulator 15 must store the compensation signals for the quadrature modulator before the calibration and keep them constant during the calibration.

Patent Claims

1. Quadrature mixer with which the quadrature components (I, Q) of a ZF input signal are converted into an output signal (A) by mixing with two superposition frequencies in quadrature with respect to one another of a local superposition oscillator (5), **characterized in** that the output signal (A) is converted by means of an analog IQ demodulator (10) to the intermediate frequency of the input signal and from the quadrature components (I, Q) in the intermediate frequency position recovered in this way

   a) the I and Q offset error is determined,

   b) by means of intermediate frequency band filters and succeeding rectifiers the I and Q imbalance errors are determined, and

   c) by multiplication of these signals obtained under b) the quadrature error is determined, and from these offset, imbalance and quadrature error values, determined in this wa,y in a regulator (15) correction values are determined with which the quadrature components of the intermediate frequency input signal are continuously corrected in error-compensating manner without the useful signal (NS) being impaired at the output (A).

2. Quadrature mixer as claimed in claim 1, characterized in that before the IQ demodulator (10) a highpass filter (41) is provided which alternatively can be switched on and off, and the inherent errors of the IQ demodulator determined with the highpass filter switched on, are stored in the regulator (15) and are considered accordingly in the error compensation of the intermediate frequency input signals without impairing the useful signal (NS).

3. Quadrature mixer as claimed in claim 1 or 2, characterized in that the output signal (A) is converted before the IQ demodulator (10) to a constant intermediate frequency ($f_{IF} + f_{ZF}$) (superposition mixer 30).

4. Quadrature mixture as claimed in one of the preceding claims, characterized in that the intermediate frequency input signal is supplied as a digital signal and the analog error values determined in the analog IQ demodulator are digitized before the regulator (15).

5. Quadrature mixer as claimed in one of the preceding claims, characterized in that before the IQ demodulator (10) an oscillator (46) is provided, which can alternatively be switched on and off, and the inherent errors of the IQ demodulator, determined with the oscillator switched on, are stored in the regulator (15) and during the error compensation of the intermediate frequency input signals are taken into consideration accordingly without impairing the useful signal (NS).

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3 sheets of drawings enclosed
